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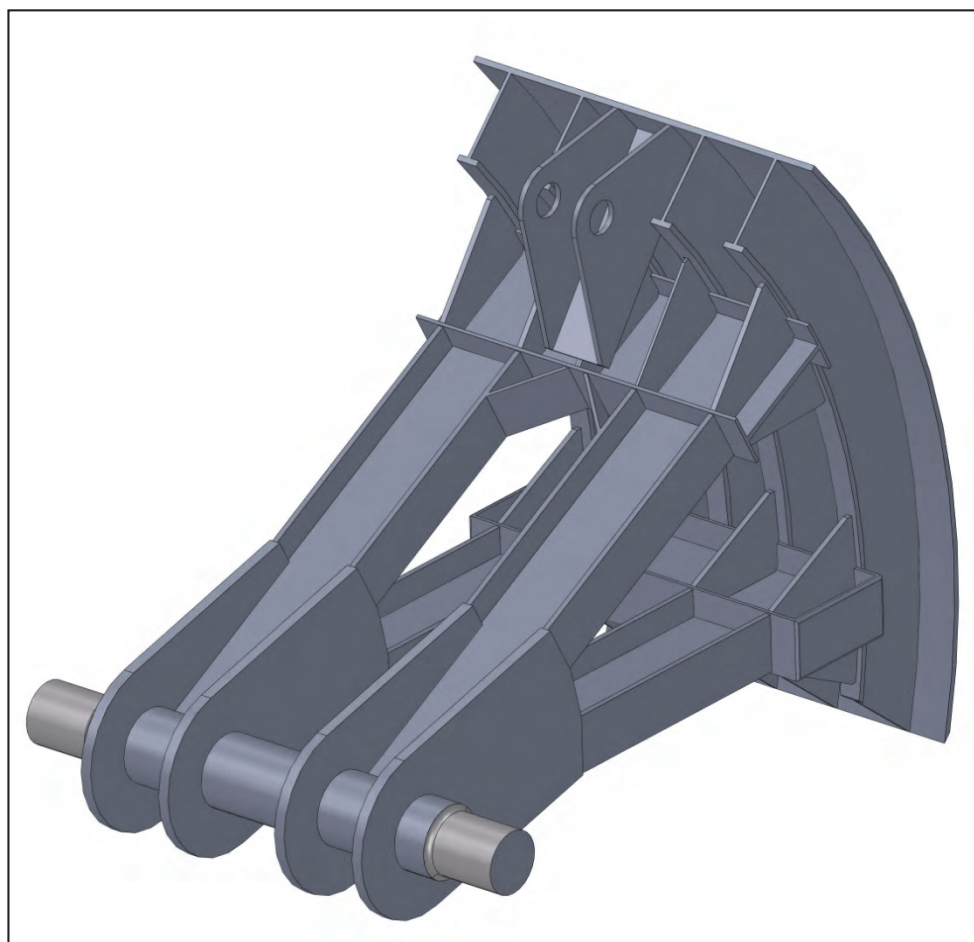
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## **Watts Bar Lock Valve Model Study**

Carlos B. Bislip-Morales and John E. Hite, Jr.

August 2013



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Final report

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## Abstract

A 1:10-scale physical model has been used to evaluate the performance of the replacement reverse tainter lock culvert valves at Watts Bar Lock and Dam on the Tennessee River. Project personnel have reported problems associated with the replacement valves during normal and emergency operations. This model study was conducted to determine the valve hoist loads during normal and emergency operations, culvert pressures downstream of the valve, and cavitation potential for various valve openings. Design modifications to improve performance were to be recommended. The model tests revealed the maximum valve hoist loads are reduced when the top seal plate is removed. A horizontal plate installed at the bottom of the valve increases valve hoist loads and valve movement for the larger openings. Tests of the original double skin-plated valve showed that the valve hoist loads were higher with the original valve. This report contains the analysis of data acquired for the original double-skin-plated valve and the replacement vertically-framed valve and subsequent modifications.

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## Preface

The investigation reported herein was authorized by the Headquarters, US Army Corps of Engineers at the request of the US Army Engineer Nashville (LRN) in September 2008. The model experiments were performed during the period June 2009 to October 2010. LRN sponsored the portion of the study involving the replacement lock valves and the Navigation Safety Initiatives Research Program sponsored the portion involving the original lock valves. The LRN proponent for the study was Tom Hood, Operations Manager for the East Tennessee River (currently assigned to IWR), and the Program Manager for the Navigation Safety Initiatives Research Program was Jeff Lillycrop. Lillycrop is also the Technical Director for Navigation in the Coastal and Hydraulics Laboratory (CHL), US Army Engineer Research and Development Center (ERDC). The model study was led by Dr. John E. Hite, Jr. and Carlos B. Bislip-Morales of the Navigation Branch, CHL, under the general supervision of Dr. William D. Martin, Director, CHL; Mr. Jose E. Sanchez, Deputy Director, CHL; Dr. Rose M. Kress, Chief of the Navigation Division, CHL; Dennis W. Webb, former Chief of the Navigation Branch, CHL, and Dr. Richard B. Styles, current Chief of the Navigation Branch, CHL. Bislip-Morales conducted the model experiments and assisted Dr. Hite in preparation of this report.

Tom Hood, Keith Holley, Ben Burnham, and Jeff Ross of the Nashville District, Corps of Engineers visited the ERDC to view the model and discuss the model results. Hood made several visits to ERDC to assist in planning and discussing model activities.

COL Kevin J. Wilson was Commander and Executive Director of ERDC. Dr. Jeffery P. Holland was Director.

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## Unit Conversion Factors

MULTIPLY	BY	TO OBTAIN
Cubic Feet	0.02831685	cubic meters
Feet	0.3048	Meters
Gallons (US Liquid)	3.785412 E-03	cubic meter
Knots	0.5144444	meters per second
Miles (US Statute)	1,609.347	Meters
Pounds (Mass)	0.45359237	Kilograms
Tons (Force)	8,896.443	Newtons
Tons (2,000 Pounds, Mass)	907.1847	Kilograms

# 1 Introduction

## Background

Watts Bar Lock and Dam is located at Tennessee River Mile 529.9, shown in Figures 1 and 2. The lock is 60 ft wide by 360 ft long with a side port filling-and-emptying system. The average lift is about 60 ft, and the maximum lift is 70 ft. The culvert dimensions are 6 ft wide by 8 ft high. The original lock valves, shown in Figure 3, were replaced in the 1990s by the newer valves shown in Figure 4. The Watts Bar valves are 6 ft wide and 8 ft high, and similar lock valves at the Chickamauga project are 8 ft wide by 8 ft high.

The replacement valves installed at Watts Bar Lock and Dam and other projects on the Tennessee River have caused operational problems. These replacement valves must follow a different operation schedule to avoid gate openings with cavitation problems. This report provides results of the recent model experiments performed on the Watts Bar Lock Valve model being used to investigate valve performance conducted between June 2008 and October 2010.

Figure 1. Aerial view of Watts Bar Lock – USACE Digital Visual Library (USACE Digital Visual Library image: 2502-60)



Figure 2. Aerial view of Watts Bar Lock – <http://www.lrn.usace.army.mil/Locations/NavigationLocks/TennesseeRiver/WattsBar.aspx>



Figure 3. Original reverse tainter valve



Figure 4. Replacement reverse tainter valve.



## Problems with Replacement Valves

Lock personnel have been forced to alter lock operation schedules from those used with the original valves. During lock operations with the original valves, the filling valves were opened in about 1.0-ft increments until a sufficient cushion of water was in the chamber. The valves were then raised to completely open. This type of operation prevented excessive water-

surface slopes in the lock chamber which would cause problems for moored vessels. With the newer valves, the filling valves are opened to about 2.0 and 2.5 ft until the chamber rises 29 ft. This operation schedule provides the cushion of water in the chamber before the valves are opened further. The valves are then raised to between 4.5 and 5.5 ft and held until the water surface is just below the upper miter sill. The valves are then completely opened. This operation causes longer filling time than occurred with the original valves.

If the replacement valves are held between 2.0 and 4.0-ft open, loud booming noises occur in the culverts, while the structure and lock machinery vibrate. Structural members were added to the upper land-side valve in an effort to streamline flow around the valve, but the noises still occurred when the filling valves were operated in the mid range openings. The noise is caused by cavitation in the culvert downstream of the filling valves. The vapor cavities that form from the low pressure below the valve collapse or implode causing the booming sound. The replacement valves also do not function adequately during an operation where the valves must be closed immediately after they have been fully-opened. As the valve is lowered into the flow from the fully-open position, the valve is suddenly pushed upward. In some cases, this sudden movement has triggered limit switches located on the stem of the lifting mechanism to shut off the power to the valve.

## **June 2008 Field Tests**

As a result of a lock-filling demonstration in March of 2007, Dr. John Hite and Terry Waller from the Engineer Research and Development Center (ERDC) and Tom Hood from the Nashville District (LRN) agreed that removing the bulkhead seals below the filling valves may allow air to be drawn into the culvert during filling operations and reduce the intensity of the cavitations and associated vibrations. Hite and Waller traveled to Watts Bar Lock and Dam during the week of 9 June 2008 to observe lock operations and the removal of bulkhead seals from the river side filling valve. A seismograph was installed on the land-side filling valve to detect vibration in the structure during lock filling. The intent was to determine if the introduction of air into the culvert would reduce the cavitation tendencies and associated vibrations. The test results revealed that even with the bulkhead seals removed, which allowed more air into the culvert, vibrations and noises still occurred during the valve opening.

## **2 Physical Model**

A physical model study was recommended to investigate the potential for cavitation and measure the hydraulic forces on the replacement valve design.

### **Purpose & Scope**

The purpose of the lock valve model study was to determine the following:

1. valve hoist loads during normal operations
2. valve hoist loads during emergency operations
3. air demand issues based on pressure measurements
4. culvert pressures downstream of the valve and cavitation potential for various valve openings
5. design modifications required to achieve desired performance
6. applicability of results to other Tennessee River locks

### **Description**

Plan and elevation views of the lock culvert section reproduced in the model are shown in Figure 5. The culvert, bulkhead slots, and valve well were constructed of transparent plastic to allow flow observation. All the lock culvert valve members were reproduced in detail with respect to size, shape, and weight and were constructed of brass. To avoid excessive friction between the valve and culvert wall, seals were not installed on the valve. Figures 6 and 7 illustrate the 1:10 scale replacement valve model used. The 1:10-scale culvert model is shown in Figures 8-10, where flow direction is indicated by white arrows. The model reproduces the lock culvert from the intake to the valve well, the upper and lower bulkheads, the valve well, the reverse tainter valve, and approximately 150-ft length of the culvert downstream of the lower bulkhead.

### **Model Operation**

A pressure tank was used to create the appropriate head on the lock valve due to the upper pool elevation. A piezometer tube was connected to the bottom of the tank, so the desired upper pool elevation could be measured. The upper pool was adjusted by changing the tank pressure. The lock chamber water-surface elevation was simulated through a downstream

Figure 5. Lock Culvert Model – Section reproduced at 1:10-scale

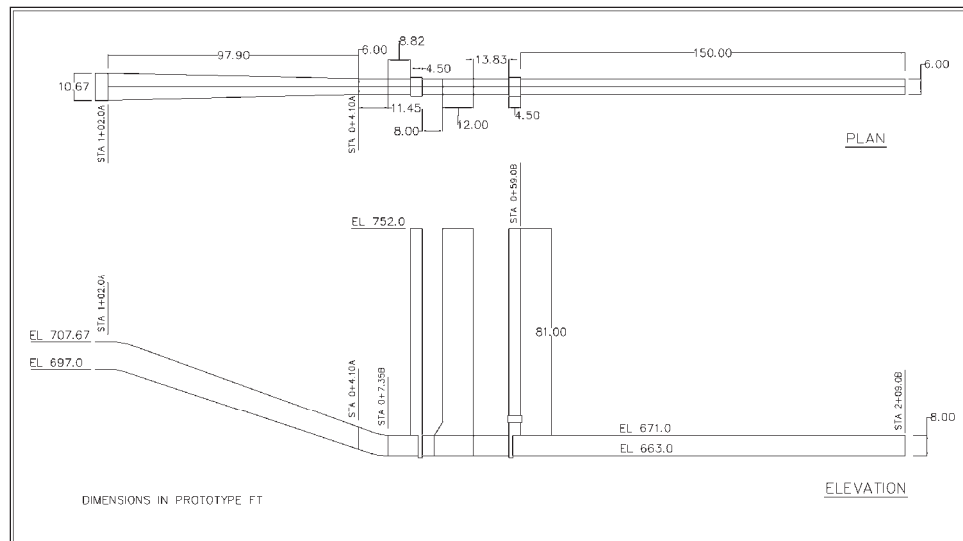


Figure 6. CAD Replacement reverse tainter valve

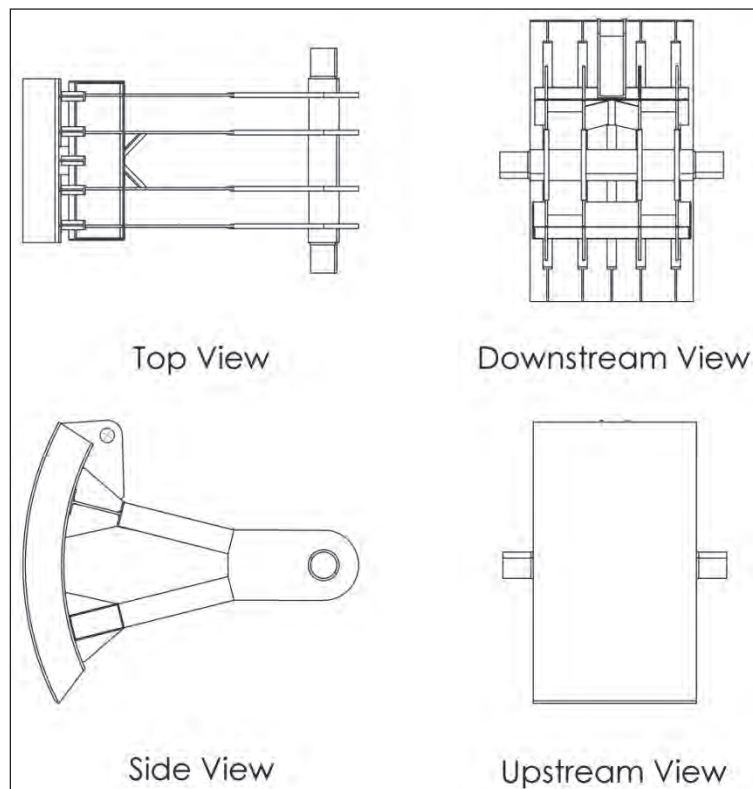




Figure 7. CAD Replacement reverse tainter valve

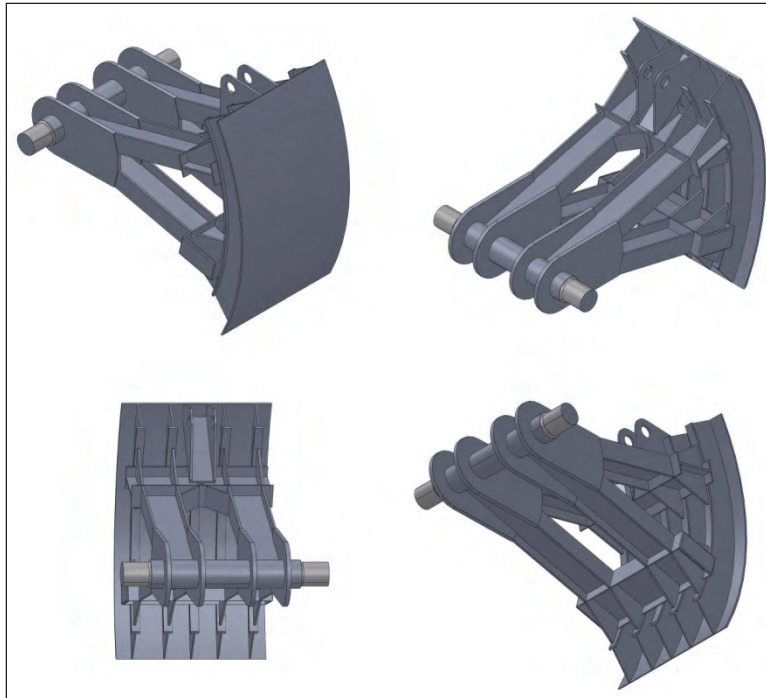


Figure 8. Lock Culvert Model – Downstream View



Figure 9. Lock Culvert/Valve Model – Side View



Figure 10. Lock Culvert Model – Upstream View

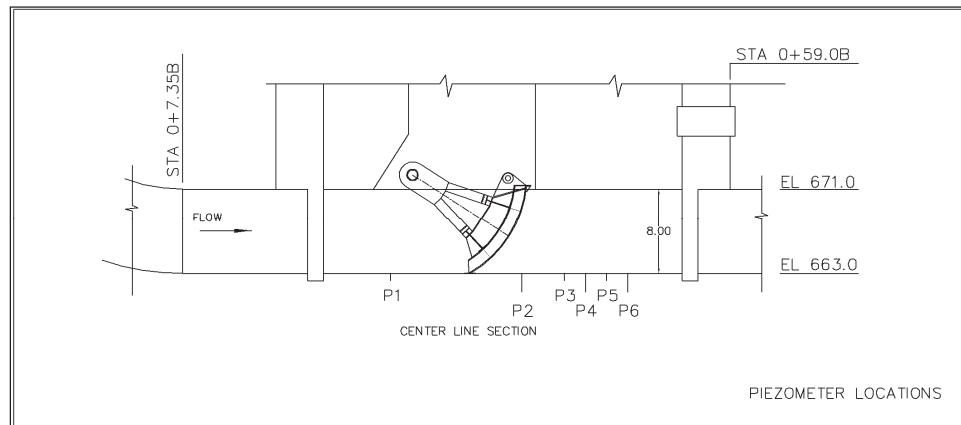


vertical control gate and measured through a piezometer installed downstream of the valve model at the base of the culvert model. Constant discharge flows were maintained, and the hydraulic loads on the valve



were measured for the varying openings and lock chamber elevations. Piezometers, shown in Figure 11, were installed on the culvert invert upstream and downstream of the valve.

Figure 11. Piezometer Locations



## Scale Relations

This study used a 1:10-scale Froudian model, where  $L_r = L_m/L_p$  (where  $L_r$  is the ratio,  $L_m$  is the model, and  $L_p$  is the prototype). Setting the model and prototype Froude numbers equal yields the relations between the dimensions and hydraulic quantities shown in Table 1.

Table 1. Froudian Similitude Relationships

Characteristic	Dimension <sup>1</sup>	Scale Relation Model:Prototype
Length	$L_r = L$	1:10
Pressure	$P_r = L_r$	1:10
Area	$A_r = L_r^2$	1:100
Velocity	$V_r = L_r^{1/2}$	1:3.162
Discharge	$Q_r = L_r^{5/2}$	1:316
Time	$T_r = L_r^{1/2}$	1:3.162
Force	$F_r = L_r^3$	1:1,000

<sup>1</sup>Dimensions are in terms of length.

## Instrumentation

A Honeywell 100-lb load cell, initially mounted between two metal rods, was used to measure hoist loads on the valve. The lower metal rod was connected to the valve lifting pin and the upper rod to the load cell. The

upper metal rod was connected to the load cell on the lower end, and the upper end of the rod was pinned to the top of the valve well. Holes were drilled in the upper rod at locations representing the valve openings, and the pin was inserted in the hole for the desired valve opening. The calibration for the load cell was checked by personnel from the ERDC Instrumentation Services Division before installation on the model. The signal from the load cell was recorded and processed electronically with WESDAQ2 software (an in-house ERDC data acquisition program).

## Test Procedure

Vertical hydrodynamic loads exerted on the lock culvert valve lift mechanism were measured for selected head and lower pool elevations. The normal upper pool elevation<sup>1</sup> of 740 ft was held constant for all initial tests, while the pressure in the culvert downstream from the valve varied from el 680 to el 720 ft. A vertical slide gate was placed in the culvert about 140 ft downstream of the operating lock valve to produce the desired culvert piezometric pressure (this piezometric will be referred to as the chamber water-surface elevation, CWSEL).

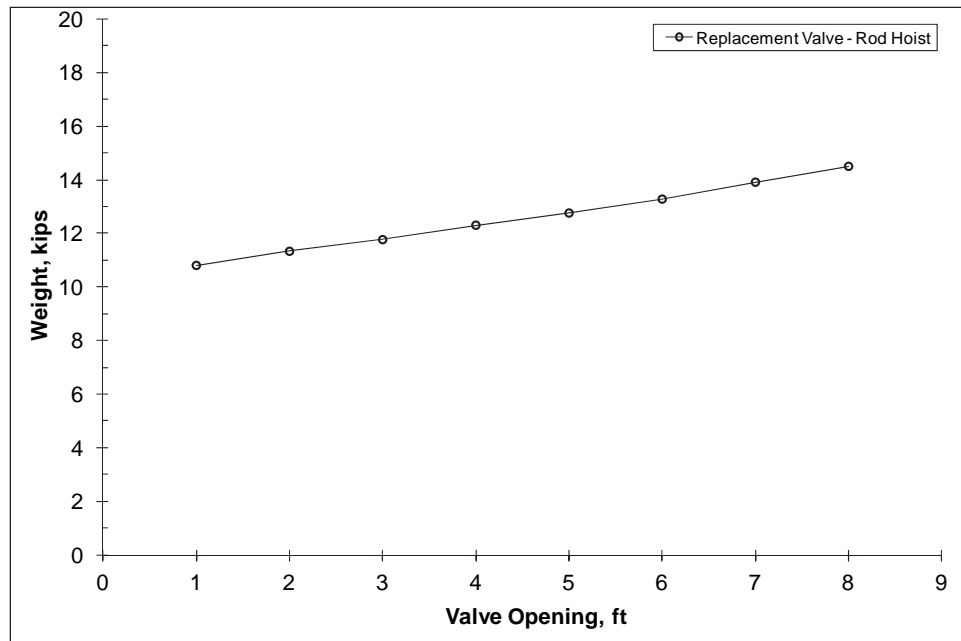
## Dry Weight Measurements

Prior to each day's testing, the dry weight of the lock valve in each gate position was measured. This procedure was repeated at the end of the day to ensure the load cell was recording properly. An aluminum rod was used to lift the valve. The rod was pinned at the desired valve opening. Though the weight of this rod was included in the dry weight recordings, the total weight of the valve was distributed between the trunnion and the lifting rod. Typical time histories for the dry weight of the valve and rod are shown in Figure 12. The dry weight of the valve and rod varied from 10.8 kips at a 1.0-ft valve opening to 14.5 kips at an 8.0-ft valve opening. This observation indicates larger trunnion support at lower gate openings.

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<sup>1</sup> All elevations (el) cited herein are in feet referenced to the National Geodetic Vertical Datum of 1929 (NGVD29).

Figure 12. Dry Weight: Replacement Valve – Rod Hoist



### 3 Results

#### Results with Rod for Lifting Mechanism

A series of hoist load time histories were recorded for each valve opening and for various lower pool elevations. A typical hoist load time history for a 2.0-ft valve opening is shown in Figure 13. The measurements were recorded at a 50-Hz sampling frequency for 1-min model time, which corresponds to 3.16 min prototype time. The average load recorded from the time history shown in Figure 13 was 25.6 kips. Hoist loads for 6.0-, 7.0-, and 8.0-ft valve openings are shown in Figures 14-16. Compared to the 8.0-ft valve opening, the 6.0- and 7.0-ft valve openings had larger hoist load fluctuations.

To determine the hydraulic load on the valve, the dry weight of the valve and rod was subtracted from the average of the hoist load time history measurements. The hydraulic load includes all hydrodynamic and buoyant forces acting on the valve. Figure 17 shows hydraulic loads measured for varying chamber water-surface elevations (CWSELs) for valve openings between 2.0 and 8.0 ft. Positive hydraulic loads indicate that the hoist load is greater than the dry weight of the valve and would tend to close the valve (i.e. push it downward). Similarly, a negative hydraulic load indicates the dry weight of the valve is less than the hoist load, and the force would tend to open the valve (i.e. push it upward). Downward forces were measured for 2.0- to 5.0-ft valve openings with CWSELs below 705 ft. With valve openings from 6.0 to 8.0 ft, upward forces were measured for all CWSELs. The maximum downward force shown in Figure 17 is 3.8 kips and occurred with a normal upper pool elevation of 740 ft, a CWSEL of 680 ft, and a 2.0-ft valve opening. The maximum upward force is 3.6 kips and occurred with an upper pool elevation of 740 ft, a CWSEL of 690 ft, and an 8.0-ft valve opening. Figure 18 shows the hydraulic load plotted against the valve opening for varying CWSELs. The downward force is reduced as the valve is opened except for the 5.0-ft opening, about 60 percent of the total valve opening. The impact of the flow with the lower structural members of the valve appears to cause increased downward forces with the 5.0-ft valve opening. In Figure 18, the transition between a downward force and an upward force is observed as the CWSEL increases with the 5.0-ft gate opening.

Figure 13. Hoist load with rod hoist: 740-ft upper pool, 690-ft CWSEL, 2.0-ft valve opening

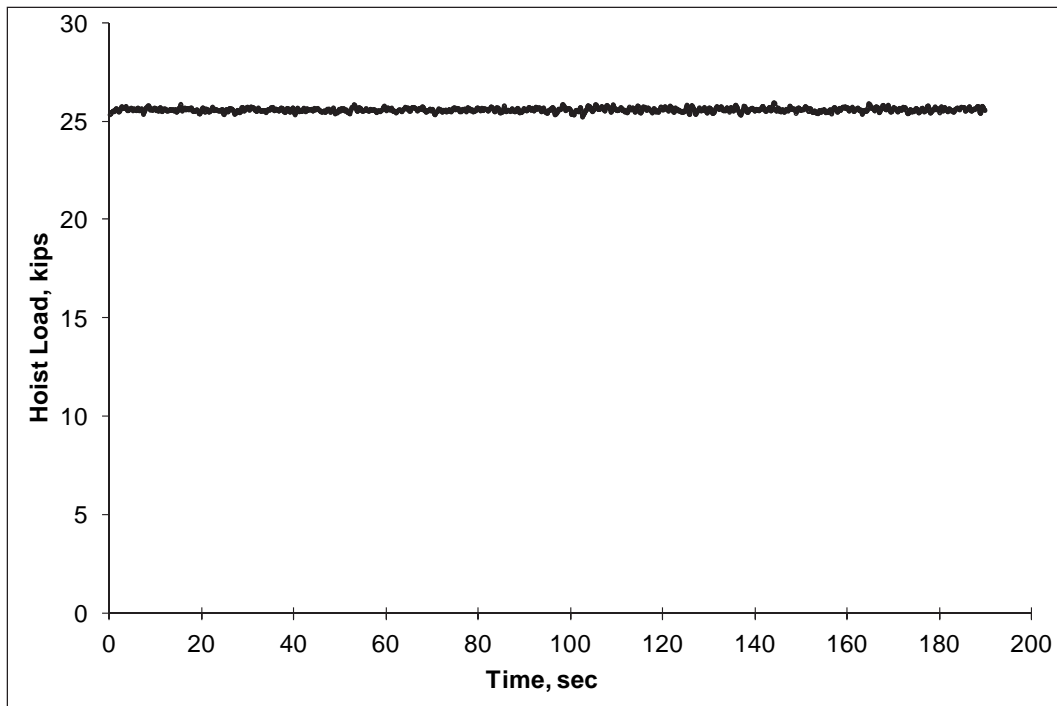


Figure 14. Hoist load with rod hoist: 740-ft upper pool, 690-ft CWSEL, 6.0-ft valve opening

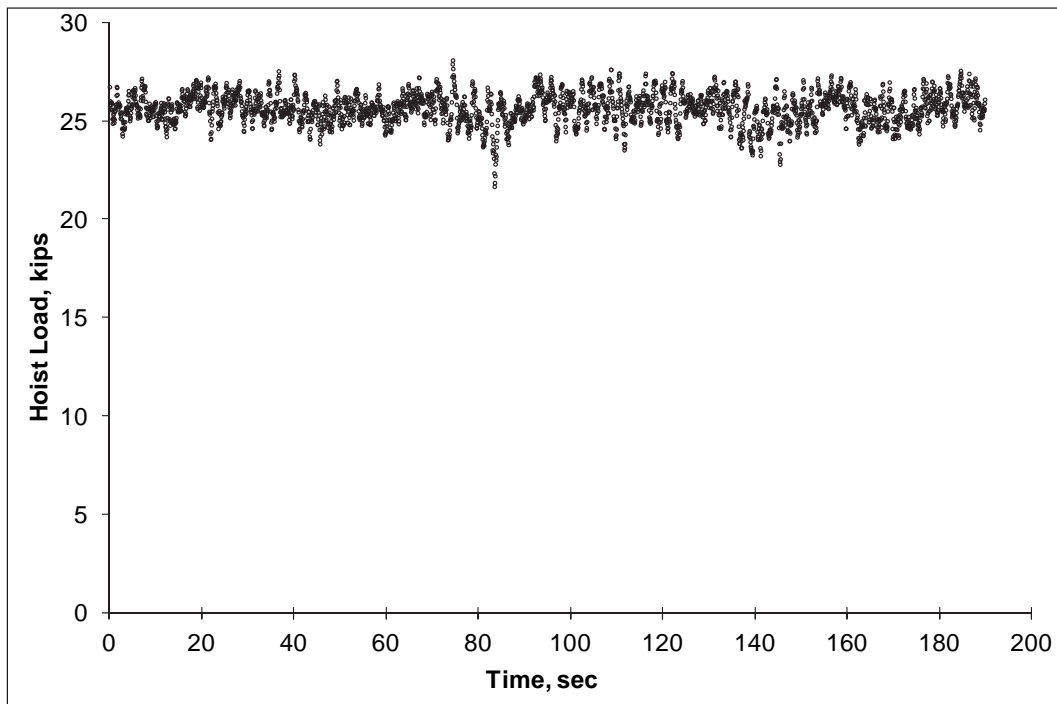


Figure 15. Hoist load with rod hoist: 740-ft upper pool, 690-ft CWSEL, 7.0-ft valve opening

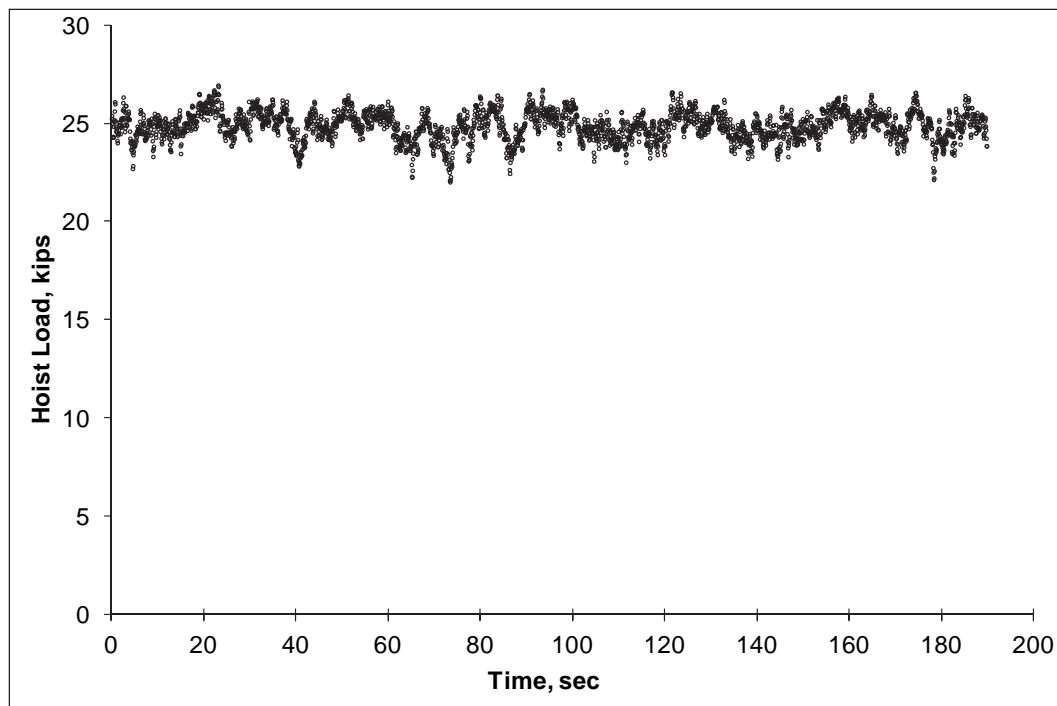


Figure 16. Hoist load with rod hoist: 740-ft upper pool, 692-ft CWSEL, 8.0-ft valve opening

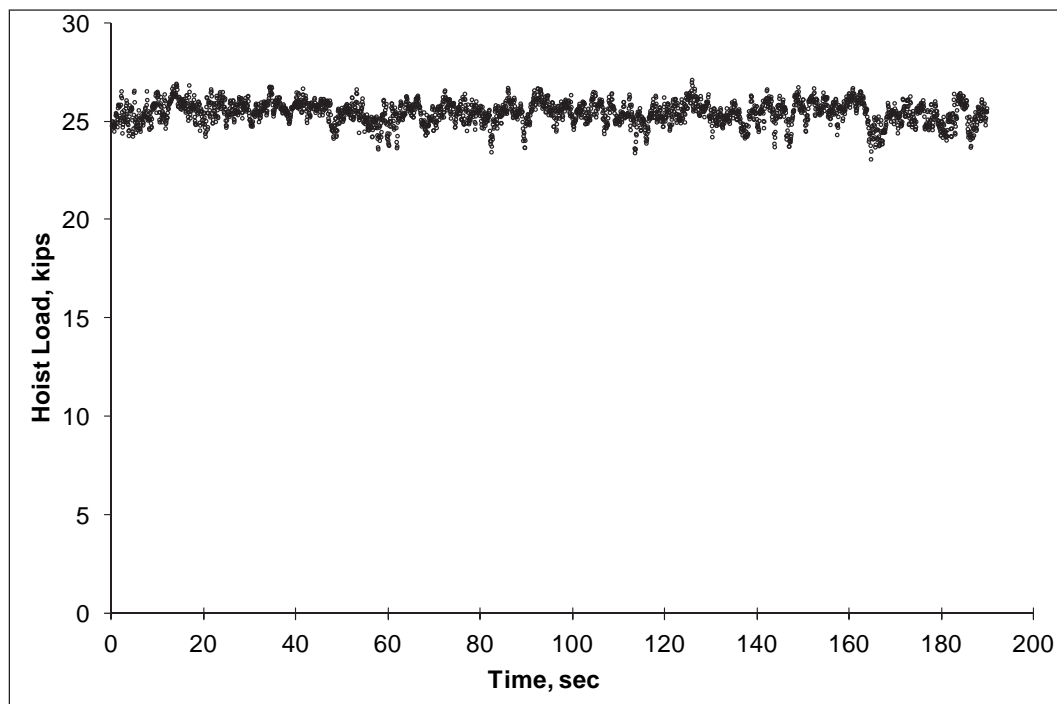


Figure 17. Chamber water-surface elevation vs. Hydraulic load with rod hoist

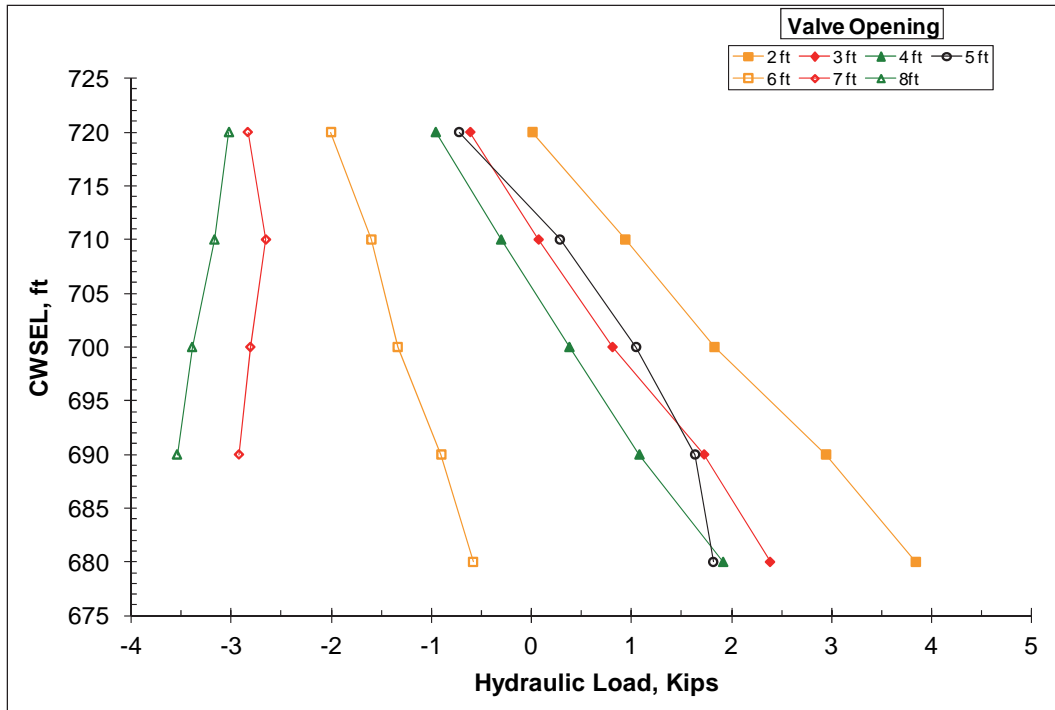
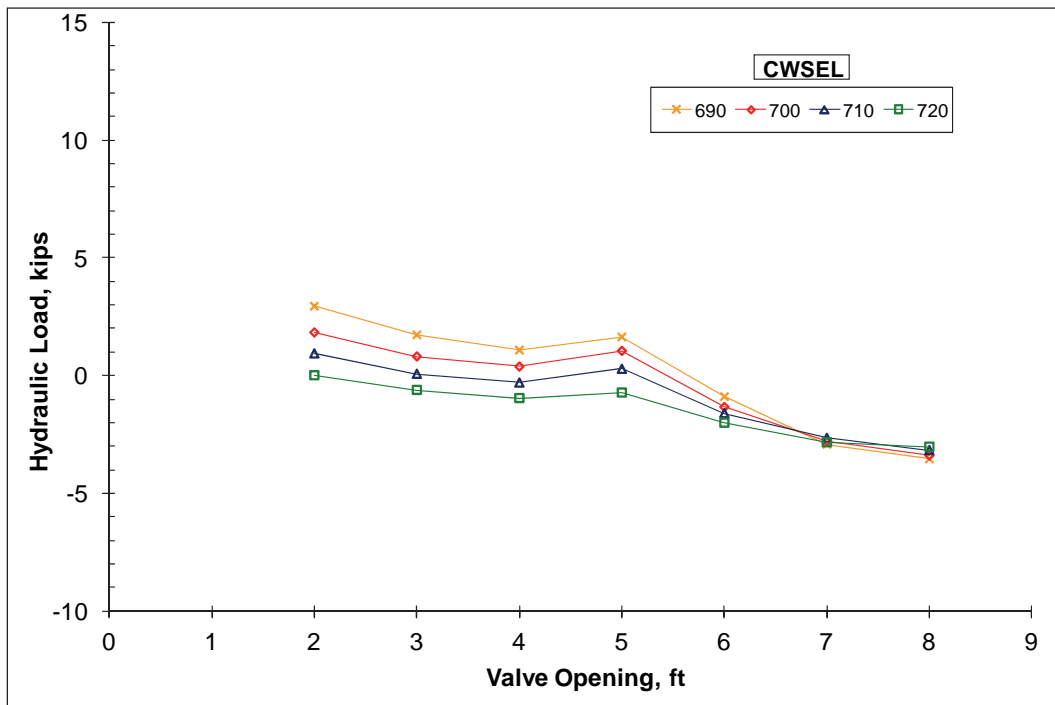


Figure 18. Hydraulic load with rod hoist vs. valve opening



## Results with Cable for Lifting Mechanism

Due to scaling effects, the rod connection could have been too rigid and its weight might have influenced the interaction of the flow with the valve. All tests were repeated with a light-weight cable used to lift the valve. The dry weight of the lock valve and cable for valve openings from 1.0 to 8.0 ft is shown in Figure 19. The dry weight of the valve and cable varied from 5.9 kips at a 1.0-ft valve opening to 9.7 kips at an 8.0-ft valve opening.

The CWSEL and hydraulic load results with the cable connection are shown in Figures 20 and 21. The maximum downward force shown in Figure 20 is 3.1 kips and occurred with the normal upper pool elevation of 740 ft, a CWSEL of 680 ft, and a 1.0-ft valve opening. The maximum upward force was 3.3 kips and occurred with an upper pool elevation of 740 ft, a CWSEL of 690 ft, and an 8.0-ft valve opening. Figure 21 shows these data plotted as hydraulic load versus valve opening for varying CWSELs. The measured forces were comparable to those with the rod lifting mechanism although the load increase at the 5.0-ft valve opening was not as noticeable.

Time histories were measured as the lock valve was lowered from fully-open (8.0-ft) to a 7.0-ft valve opening. The electric winch used to lower the lock valve did not have a speed controller, so the valve could not be stopped exactly on the 7-ft valve opening. Figure 22 shows the hoist loads measured during the first test. The noticeable load spikes between 65 and 80 secs are thought to have occurred when the valve was started and stopped. A second test was performed to compare to the initial test, and the measurements from this test are shown in Figure 23. The load spikes were noticed again around 40 secs. Since the load spikes may have been caused by the electric winch, a manually-operated winch was used to control the valve position more closely.

## Valve Lowering with Manual Winch

The electric winch was replaced with a manually-controlled winch to perform additional dynamic tests. Figure 24 shows a time history obtained while lowering the valve from 8.0 to 7.0 ft open with an initial CWSEL of 690 ft. The valve was lowered from 8.0 to 7.0 ft between 100 and 160 seconds at a speed of about 1.0 ft/min. No large hydraulic load fluctuations were observed during the valve lowering, which indicates that the manual winch worked better for this type of test. The loads measured during valve lowering did not show any significant hydraulic load fluctuations that would cause the reported sudden upward valve movement.



Figure 19. Dry Weight: Replacement Valve – Cable Hoist

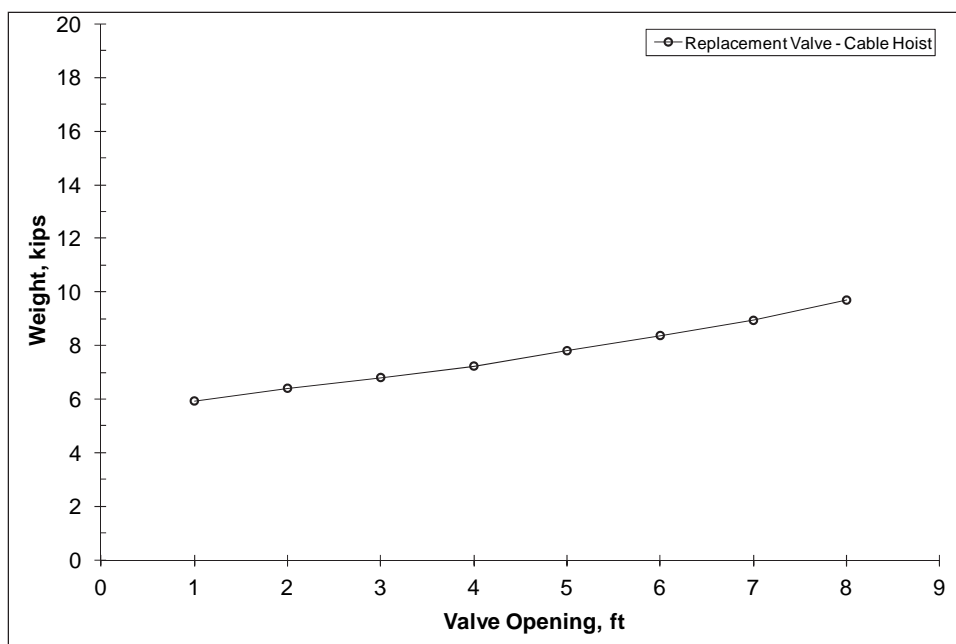


Figure 20. Chamber water-surface elevation vs. Hydraulic load with cable hoist

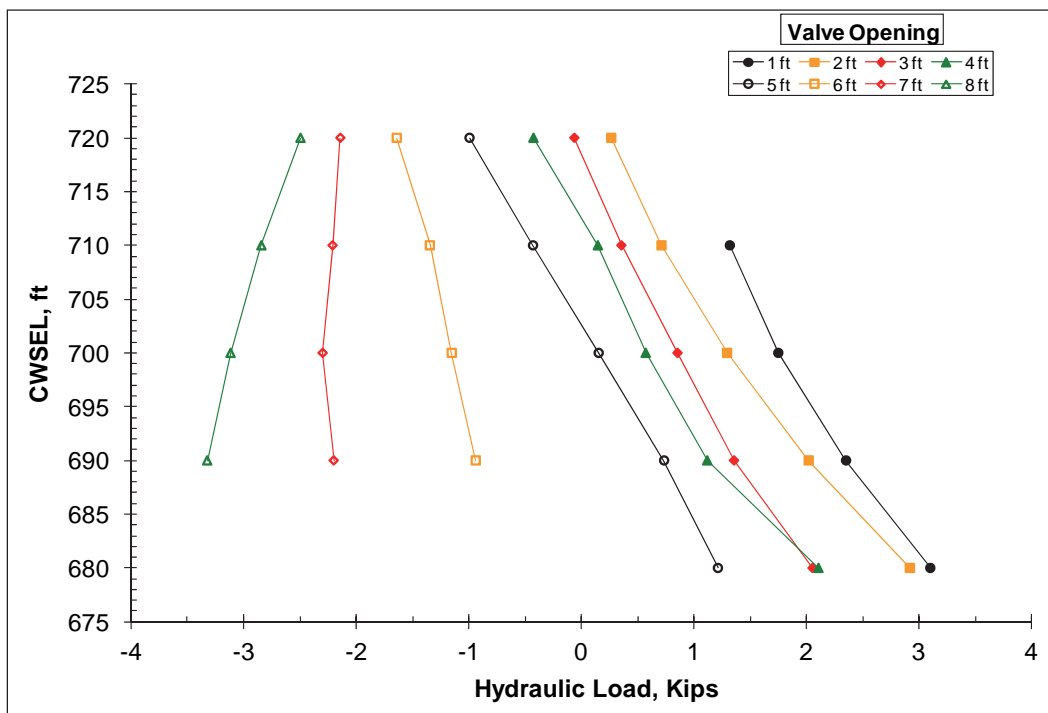


Figure 21. Hydraulic load with cable hoist vs. valve opening

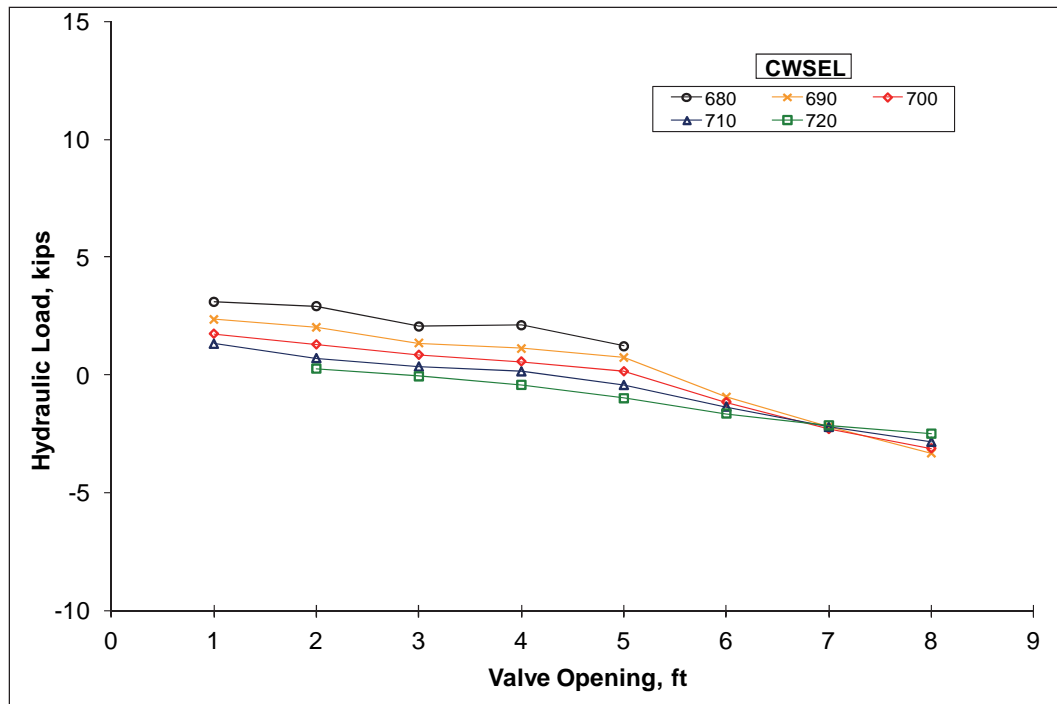


Figure 22. Unsteady hoist load measurements: 8.0 ft – 6.8 ft

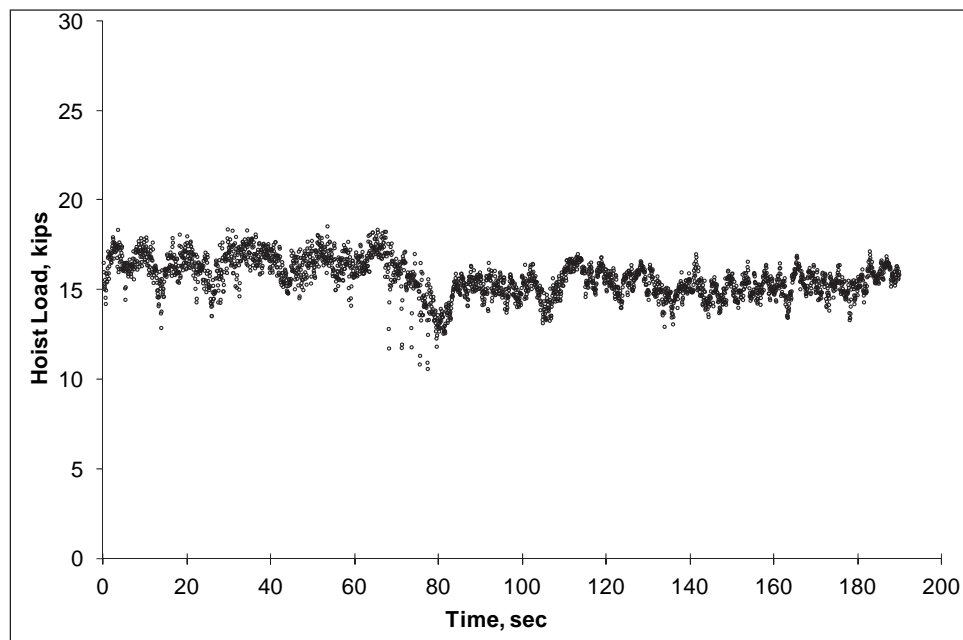


Figure 23. Unsteady hoist load measurements: 8.0 ft – 7.0 ft

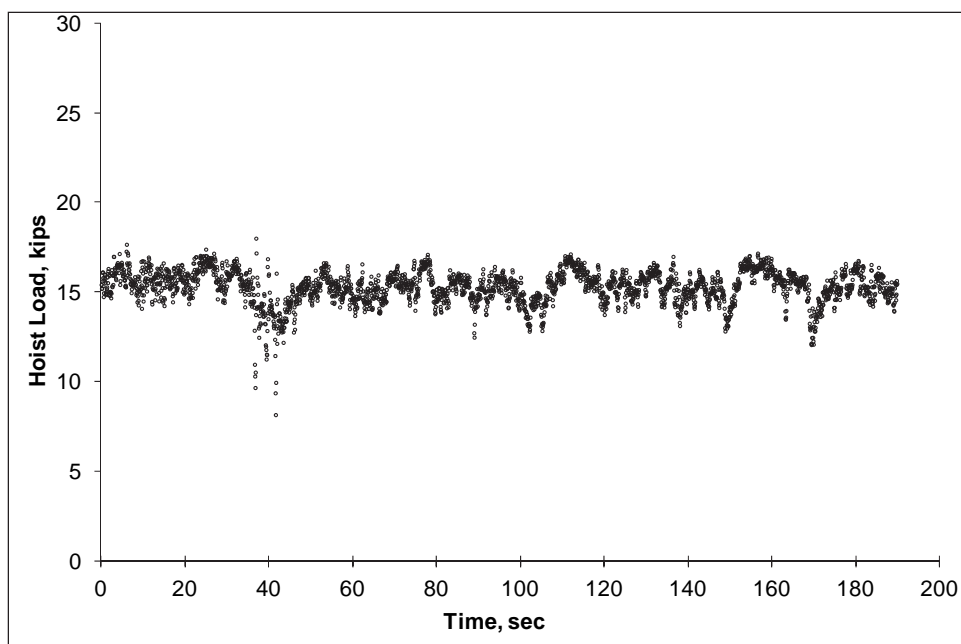
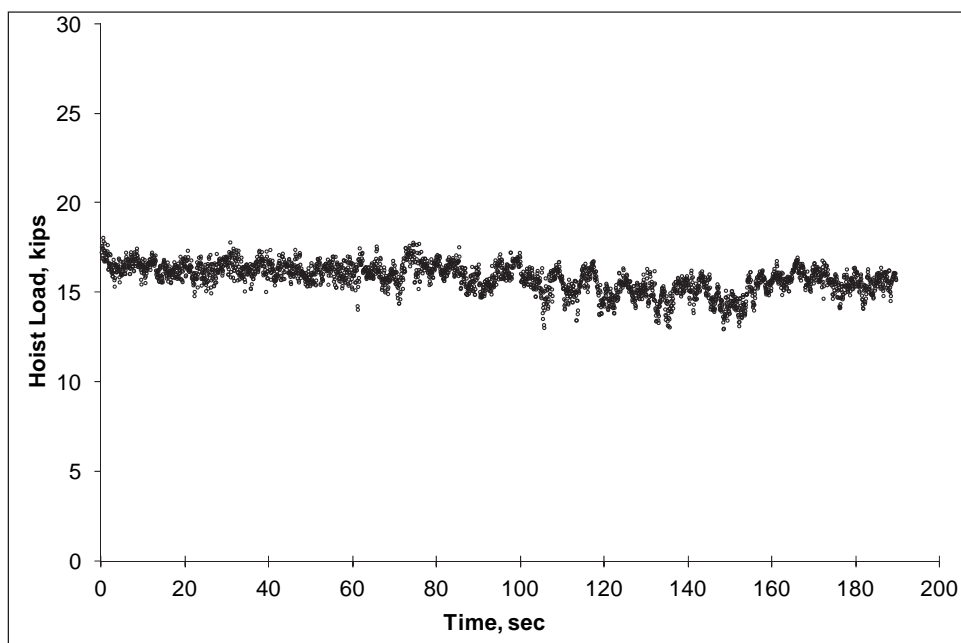


Figure 24. Unsteady hoist load measurements: 8.0 ft – 7.0 ft, Manual Winch



## Piezometer Readings

Piezometers were installed on the culvert invert to measure the piezometric pressure in the culvert for selected valve openings and CWSELs. The piezometer locations are shown in Figure 11. Piezometer readings for 2.0-, 3.0-, 4.0-, 5.0-, and 6.0-ft valve openings are shown in table form in Figures 25 and 26. Pressures downstream from the valve as

low as el 644 ft were measured with a 4.0-ft valve opening and a CWSEL of 680 ft at piezometer location P4. A plot of piezometer readings at P4 for CWSELs between 680 ft and 720 ft are shown in Figure 27. The pressure at P4 with a CWSEL of 680 ft is 19 ft lower than the culvert invert and indicates that cavitation is possible in the prototype.

Figure 25. Piezometer readings for 2.0-, 3.0-ft valve openings with 740-ft upper pool

2-FT VALVE OPENING						3-FT VALVE OPENING					
PIEZ. NO.	CWSEL					PIEZ. NO.	CWSEL				
	680	690	700	710	720		680	690	700	710	720
PIEZOMETER READING						PIEZOMETER READING					
1	737	738	738	739	739	1	733	734	736	737	738
2	666	679	691	704	715	2	671	683	694		717
3	663	676	688	702	714	3	655	669	683	697	712
4	661	674	687	701	714	4	652	668	681	696	711
5	662	675	688	702	714	5	652	669	682	696	711
6	661	674	687	701	714	6	652	668	681	696	711

PIEZOMETER READINGS FOR 2- AND 3-FT VALVE OPENINGS

Figure 26. Piezometer readings for 4.0-, 5.0-, and 6.0-ft valve openings with 740-ft upper pool

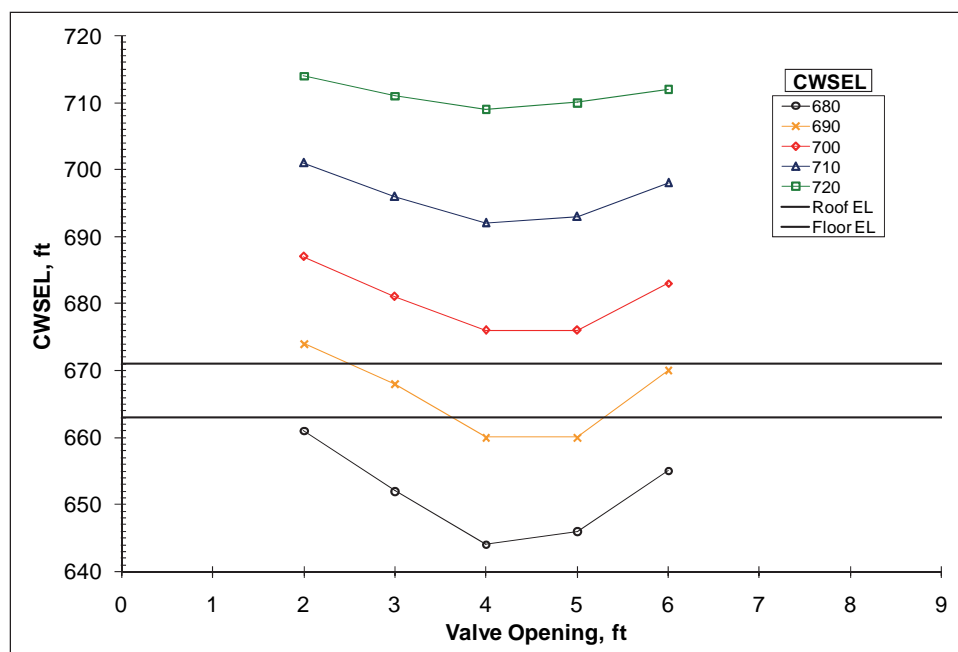
4-FT VALVE OPENING						5-FT VALVE OPENING					
PIEZ. NO.	CWSEL					PIEZ. NO.	CWSEL				
	680	690	700	710	720		680	690	700	710	720
PIEZOMETER READING						PIEZOMETER READING					
1	726	729	731	733	735	1	716	719	723	728	732
2	676	687	698	709	719	2	676	687	697	709	720
3	651	665	681	696	711	3	657	668	682	697	712
4	644	660	676	692	708	4	646	660	676	693	710
5	645	661	678	693	709	5	646	660	676	693	710
6	644	661	677	693	709	6		660	676	693	710

6-FT VALVE OPENING					
PIEZ. NO.	CWSEL				
	680	690	700	710	720
PIEZOMETER READING					
1	705	710	716	722	728
2	688	687	698	709	719
3	661	675	688	701	713
4	655	670	683	698	711
5	656	671	684	699	712
6	657	672	685	700	712

PIEZOMETER READINGS FOR 4-, 5-, AND 6-FT VALVE OPENINGS

Figure 27. P4 Piezometer readings



## Meeting with Nashville District Personnel

A meeting was held in June 2009 to discuss model results and plan additional model tests. At this meeting the attendees discovered that the prototype valve had a structural plate as shown in Figure 28. The prototype valve had the adjustment bolts for the top seal mounted on the top downstream side of the plate. This plate was not in place on the model valve. The valve was removed and the top seal plate was added to the model valve as shown in Figure 29.

## Model Results with Top Plate Installed

Tests were performed with the top plate installed on the model valve. The hydraulic loads determined from these tests are shown in Figures 30 and 31. The maximum upward force measured occurred with an 8.0-ft valve opening and a CWSEL of 685 ft. Upward forces were higher than the ones measured previously without the top plate installed. The top plate was increasing the upward forces for the higher valve openings and slightly decreasing the downward forces with the lower valve openings. Figure 32 shows a time history of the hoist load while the valve is lowered from an 8-ft (fully open) to a 7.0-ft valve opening. The lowering took place between 80 and 140 secs on the time history. The average hoist load did not significantly change before and after the valve was lowered. Between 0 and 80 secs, the average hoist load was 14.5 kips and between 140 and 240 secs the average

Figure 28. Plate with top seal adjustment bolts

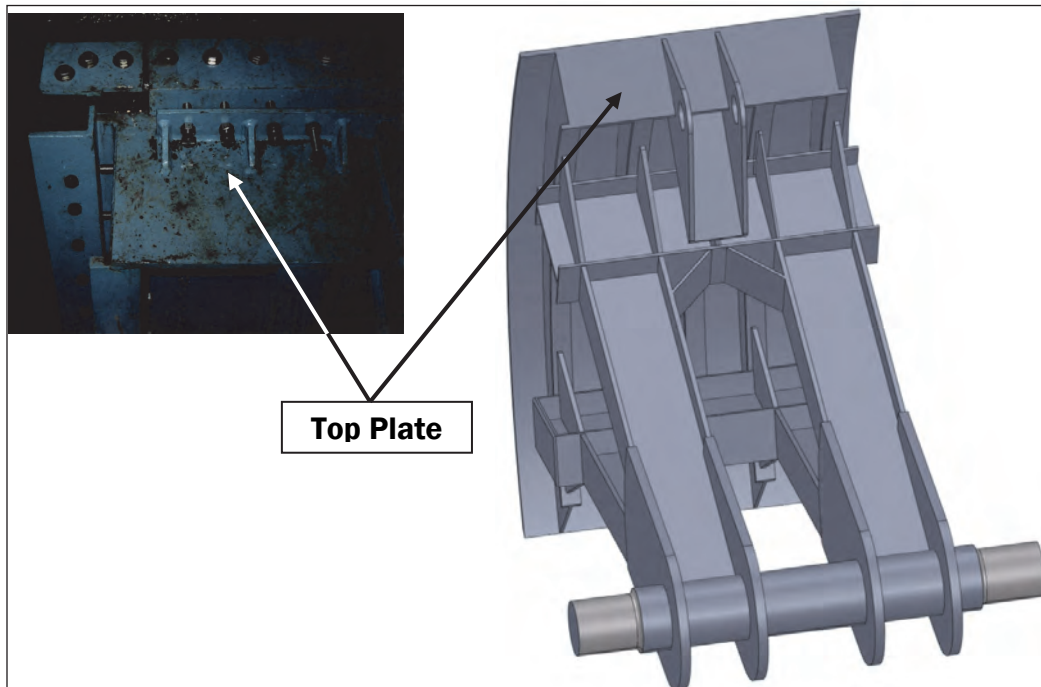


Figure 29. Lock Valve Model – Top plate installed on Replacement Valve

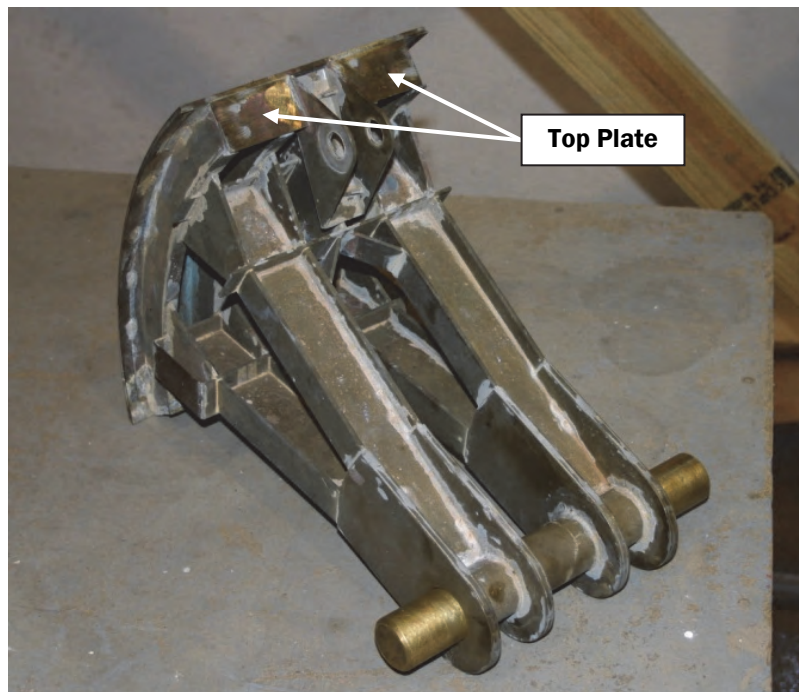


Figure 30. Chamber water-surface elevation vs. Hydraulic load with top plate

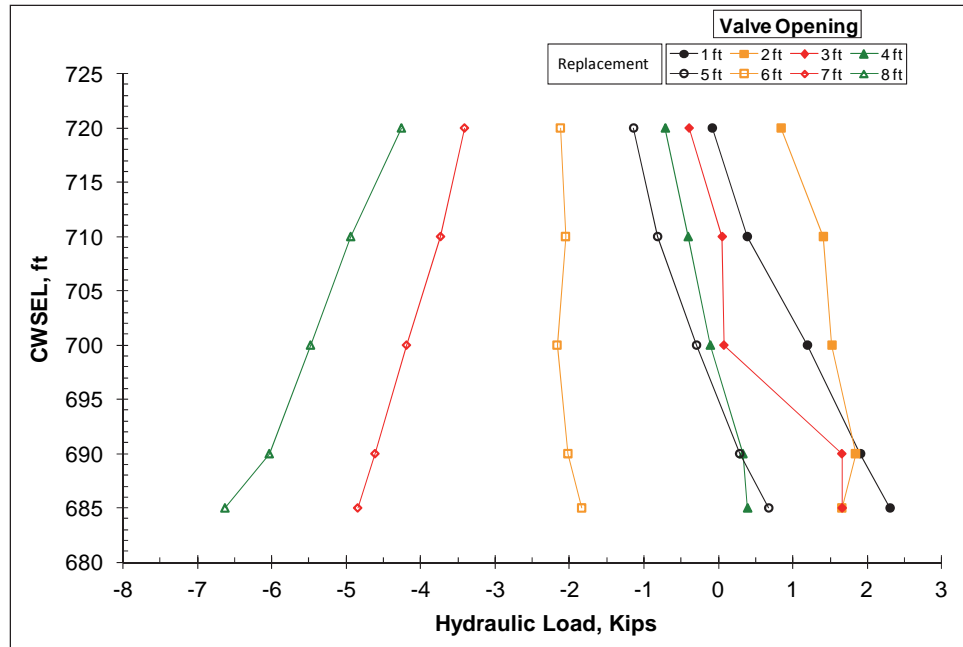


Figure 31. Hydraulic load vs. valve opening with top plate

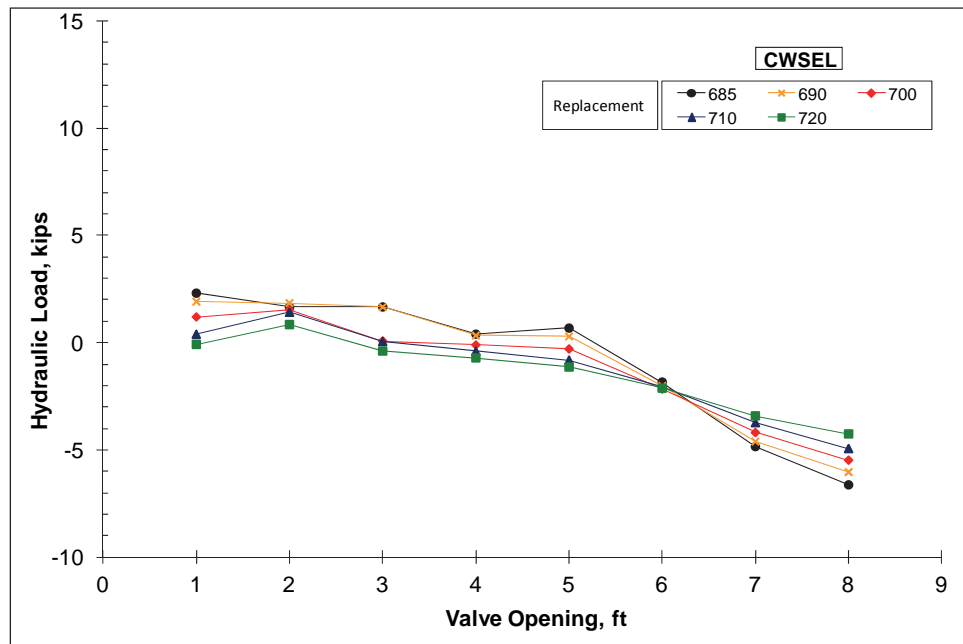
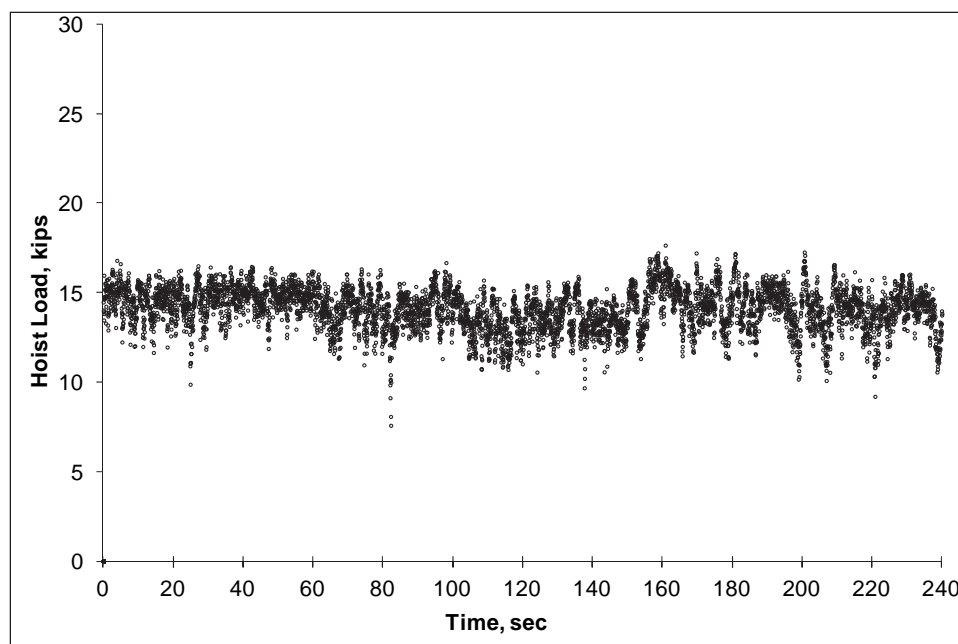


Figure 32. Unsteady hoist load measurements with top plate: 8.0 ft – 7.0 ft



hoist load was 14.1 kips. An drastic reduction in hoist load occurred at 82.3 secs when a value of 7.6 kips was measured. This sudden change in hoist load is thought to have caused the valve movement observed at the project. At an 8.0-ft valve opening, the valve position fluctuated as a response to the hydraulic load. This movement was not seen at the lower valve openings.

### Bottom Plate Installed

In previous years various modifications have been made to the replacement valves to reduce the upward forces seen while lowering the valves under flowing water conditions. Figure 33 shows an example of the type of modifications that have been done at the Chickamauga Lock Project. The Chickamauga valve is 2.0 ft wider than the Watts Bar valve. Plates have been added to the lower portion of the valve to reduce valve oscillations as flow moves upward through the valve body. A horizontal plate was installed at the bottom of the valve between the vertical ribs and skin plate as shown in Figure 34.

### Model Results with Top Seal Plate and Bottom Plate

Data were obtained with 1.0-, 4.0- and 8.0-ft valve openings to compare with those obtained with the top seal installed. The hydraulic loads measured with these modifications are shown in Figures 35 and 36. The maximum upward and downward forces were higher with the bottom plate



installed. Higher downward forces were measured with the 4.0-ft valve opening and slightly larger upward forces were observed with the 8.0-ft valve opening as shown in Figure 37. Valve observation at an 8.0-ft opening revealed a noticeable “bouncing”. This movement was much more significant than observed with only the top plate installed. The bottom plate was not a desirable feature for the valve since it increased the maximum hydraulic forces and valve movement at the 8.0-ft valve opening.

Figure 33. Example of modifications to Chickamauga Lock valve



Figure 34. Lock Valve Model – Bottom plate installed on Replacement Valve

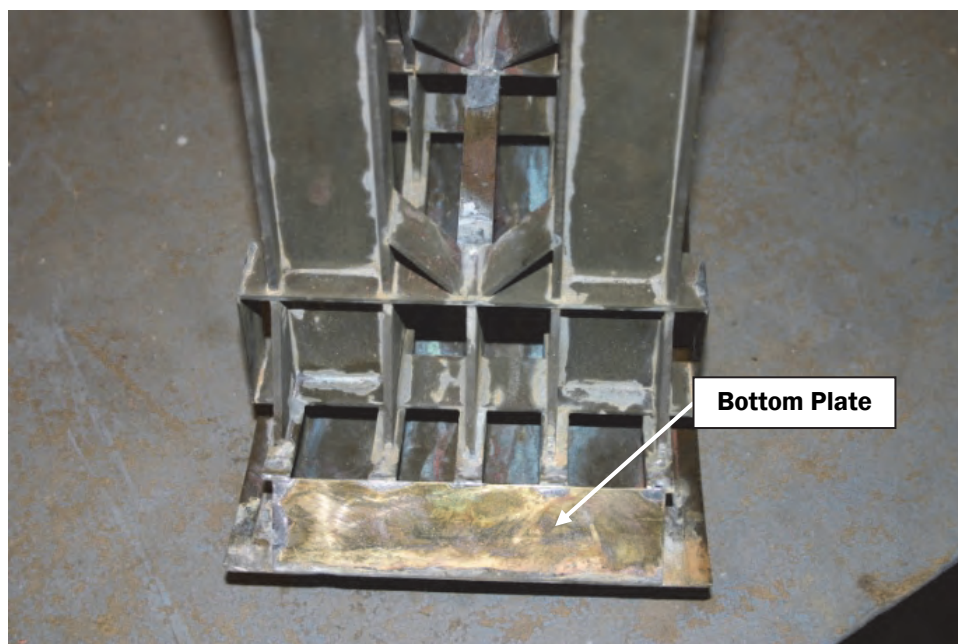


Figure 35. Chamber water-surface elevation vs. Hydraulic load with top &amp; bottom plate

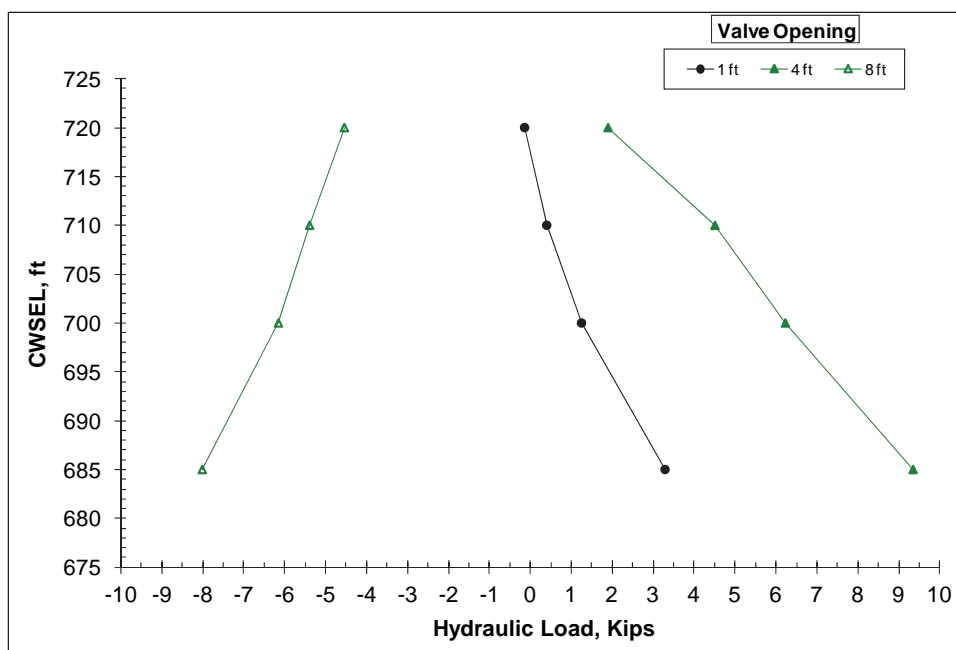


Figure 36. Hydraulic load vs. valve opening with top &amp; bottom plate

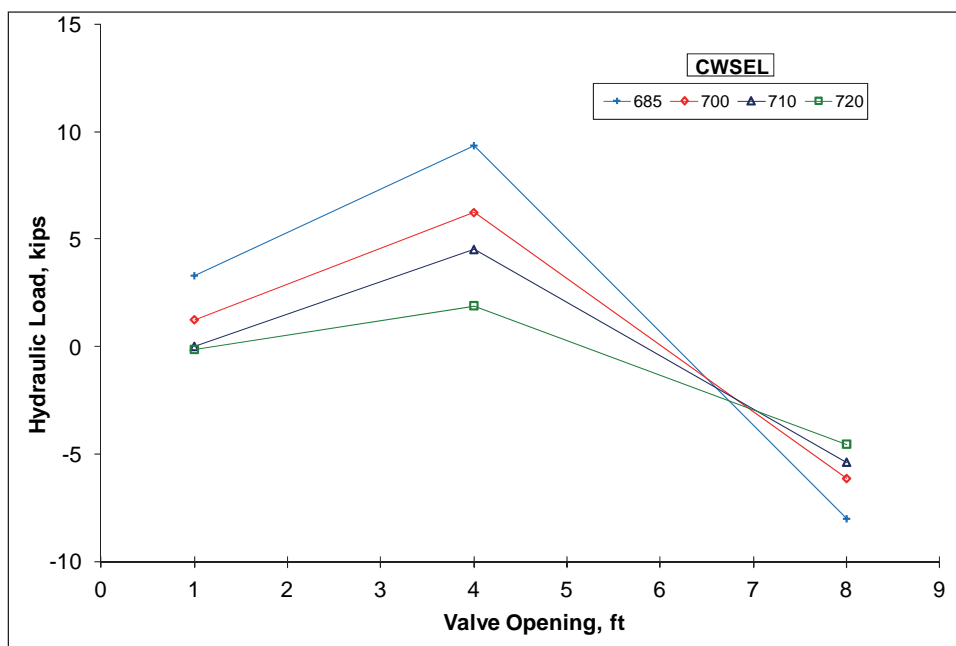
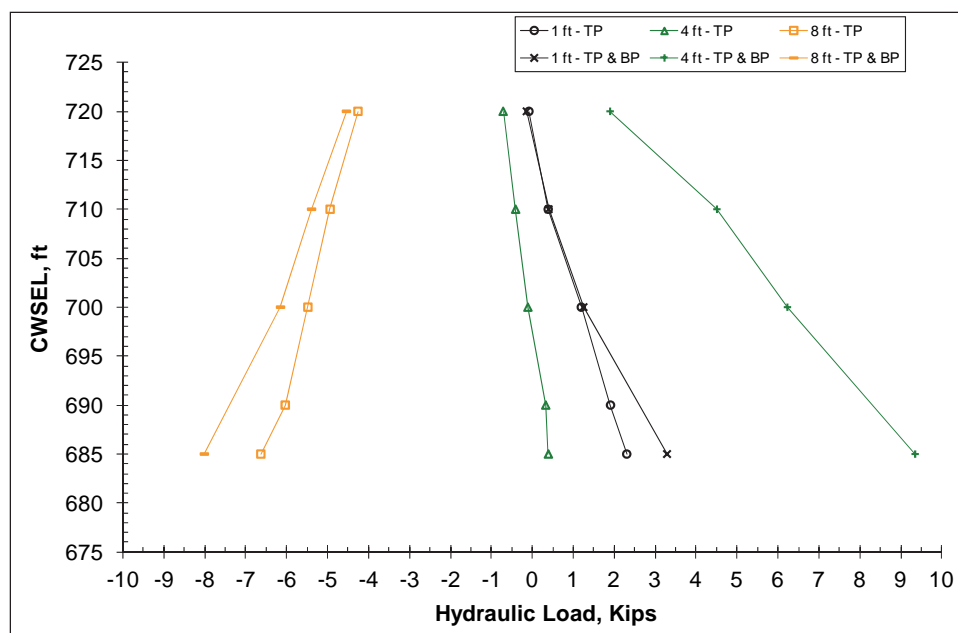


Figure 37. Select hydraulic loads for top plate and top &amp; bottom plate



## Summary of Results with Replacement Valve

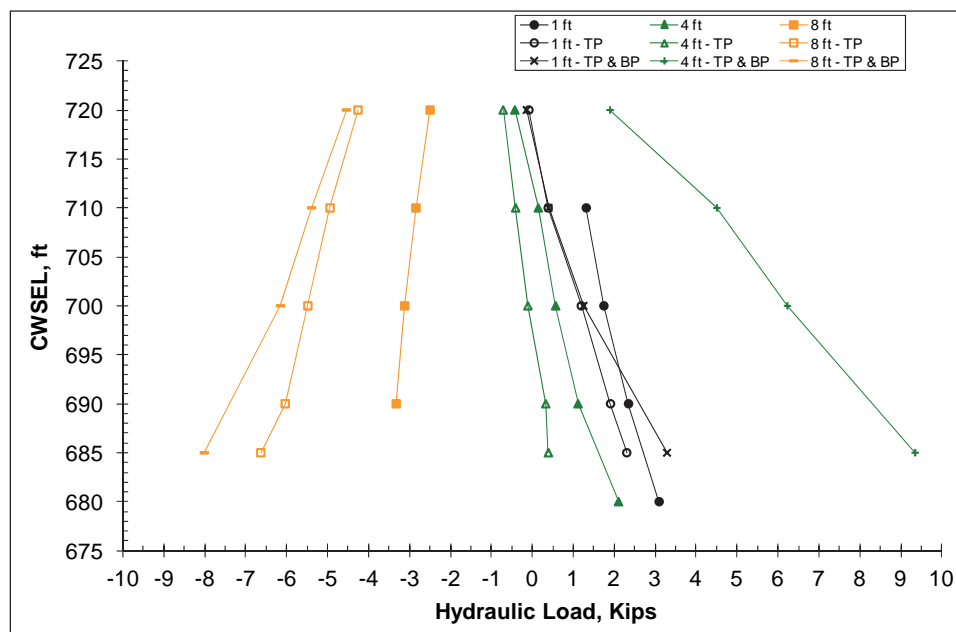
The model tests performed on the replacement valve were conducted to identify possible causes of problems associated with valve operations for both normal and emergency operations. The initial replacement valve was constructed without the top seal plate installed. This omission was an oversight because this type of valve model is constructed without side or top seals to minimize friction effects in the section model caused by the seals. Ideally, friction effects are negligible in the model. The valve performance based on constant discharge hydraulic loads was considered to be sufficient without the top seal plate. Uplift forces were less than 4 kips with the 8.0-ft valve opening, and the maximum downward load was slightly above 3 kips with the 1.0-ft valve opening. The unsteady flow tests did not show any sudden upward movement.

The top seal plate generally caused an increase in the upward forces acting on the valve. The downward loads were smaller for the lower valve openings, and the upward forces were higher for the larger valve openings. The unsteady tests indicated a significant upward force soon after the valve was lowered into the flow. The average hydraulic force before the valve was lowered was 14.5 kips and a 7.6-kip force was measured just after the valve was lowered. The upward flow along the upstream face of the valve impacts the top seal plate causing additional upward load on the valve. Observations

of the valve in the fully-open position showed movement of the valve with CWSELs between 685 and 690 ft.

The addition of the bottom plate to the valve increased the downward loads for the lower valve openings and the upward forces for the higher valve openings. Figure 38 shows a comparison of the hydraulic forces measured with the initial design, the top seal plate, and the top and bottom plates for 1.0-, 4.0- and 8.0-ft valve openings. The increase in downward load for the 4.0-ft valve opening was the most obvious change. The hydraulic force measured at a CWSEL of 685 ft and a 4.0-ft valve opening for the top plate was 0.4 kips and increased to 9.5 kips with the bottom plate installed. A slight increase in upward forces for the 8.0-ft valve opening was also measured with the bottom plate installed. The hydraulic force measured at a CWSEL of 685 ft and an 8.0-ft valve opening for the valve with the top plate increased from an upward load of 6.7 kips and to an upward load of 8.0 kips with the bottom plate installed. The bottom plate installation was not considered an improvement for the valve performance.

Figure 38. Select hydraulic loads for initial design, top plate, and top & bottom plate



The replacement valve load measurements showed that the best design was one without top or bottom plates. A top seal adjustment process that does not require such a large top plate should be developed for future use. The bottom plates should be removed from the valves on which they have

been installed when the lock is dewatered for maintenance. The constant discharge pressure measurements indicate a potential for cavitation at mid-range valve openings and low CWSELs. The culvert near the valve should be inspected carefully for possible cavitation damage when the culvert is dewatered. The combination of mid-range valve openings and low CWSELs should be avoided if possible.

### Original Reverse Tainter Valve Design

Since differences in valve performance between the original and replacement designs had been reported, a model of the original valve was constructed and the associated hydraulic forces were measured. A 1:10-scale model was constructed to fit in the existing culvert valve well. CAD drawings of the valve are shown in Figures 39 and 40. Figure 41 shows an in-place side view of the model valve.

Similar to the replacement valve, the original valve model was constructed of brass with a 1:10 scale. The trunnions for this valve were in the same location as the replacement valve although there were minor differences where the top of the valve sealed against the valve well. These differences did not allow forces to be measured at the fully-open valve position.

Figure 39. CAD Original reverse tainter valve

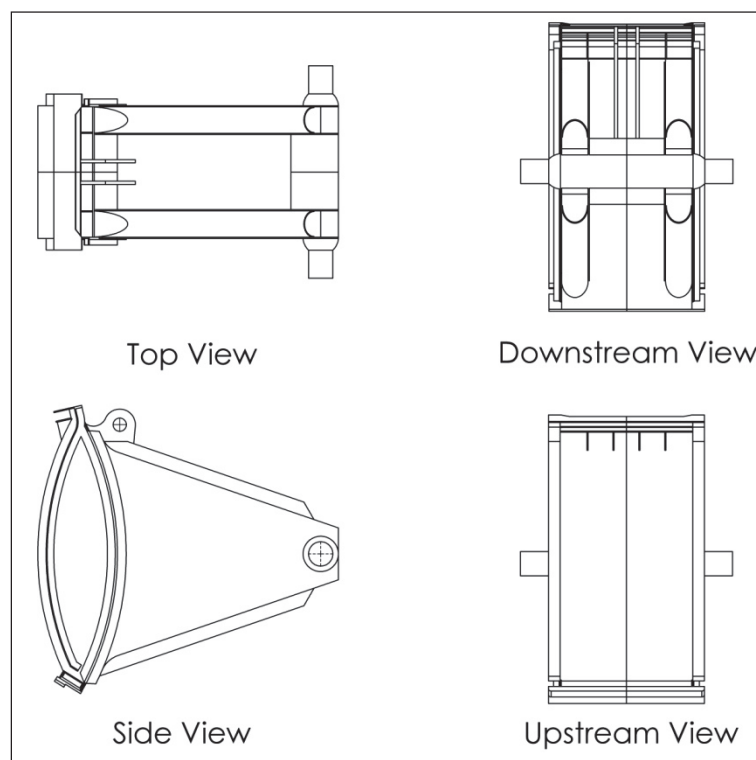




Figure 40. CAD Original reverse tainter valve

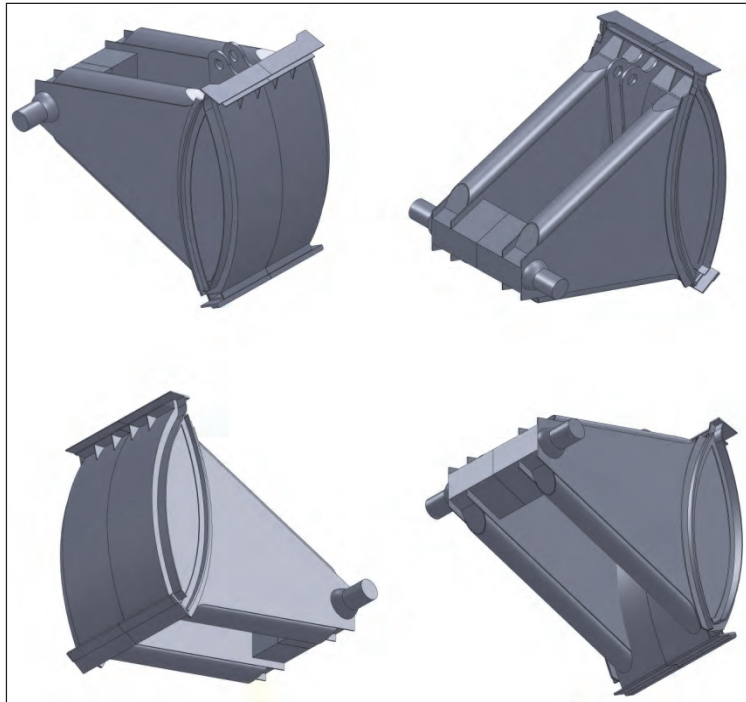
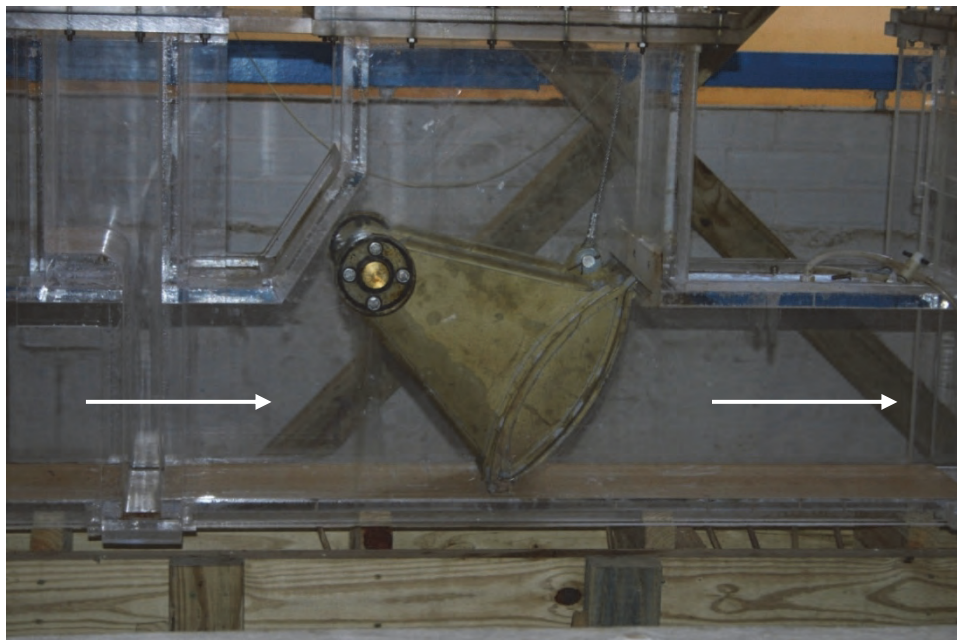


Figure 41. Lock valve model – Side View, Original reverse tainter valve



The original double skin-plated valve had streamlined curved features and enclosed structural members along the valve arms. These double skin-plate and enclosed arms allowed, for the most part, continuous flow around the valve, including the rear concave plate. Unlike the replacement valve, this feature yields a cleaner separation for flow over and under the valve.

## Force Measurements with the Original Design Valve

Hoist loads and hydraulic loads were measured with the original valve in a similar manner as described previously for the replacement valve. The hoist load from the dry weight of the original valve is shown in Figure 42. Figures 43 and 44 show the hydraulic load measurements. The valve filled with water before the hoist load measurements were made. For lower CWSELs (685 ft to 710 ft), the hydraulic loads are consistently upward for 1.0- to 5.0-ft valve openings. For a 6.0-ft valve opening, all hydraulic loads pushed the valve upward with larger forces than the loads measured from the initial replacement valve. By extension, hydraulic loads experienced by the original valve at 7.0- and 8.0-ft valve openings are expected to have a magnitude greater than those experienced by the initial replacement valve with top and bottom plates.

A comparison of the hydraulic loads measured with the replacement valve with the top seal plate installed and the original valve is shown in Figure 45 for 1.0-, 4.0-, and 7.0-ft valve openings. The most significant differences were the hydraulic loads measured with the 1.0-ft valve opening. The hydraulic load increased from 2.3 to 13.4 kips with a CWSEL of 685 ft and from 0.0 to 6.6 kips with a CWSEL of 720 ft. As observed in Figure 45, hydraulic loads were slightly higher with the original valve for the 4.0-ft valve opening and slightly lower with the original valve for the 7.0-ft valve opening.

Figure 42. Dry Weight: Original Valve – Cable Hoist

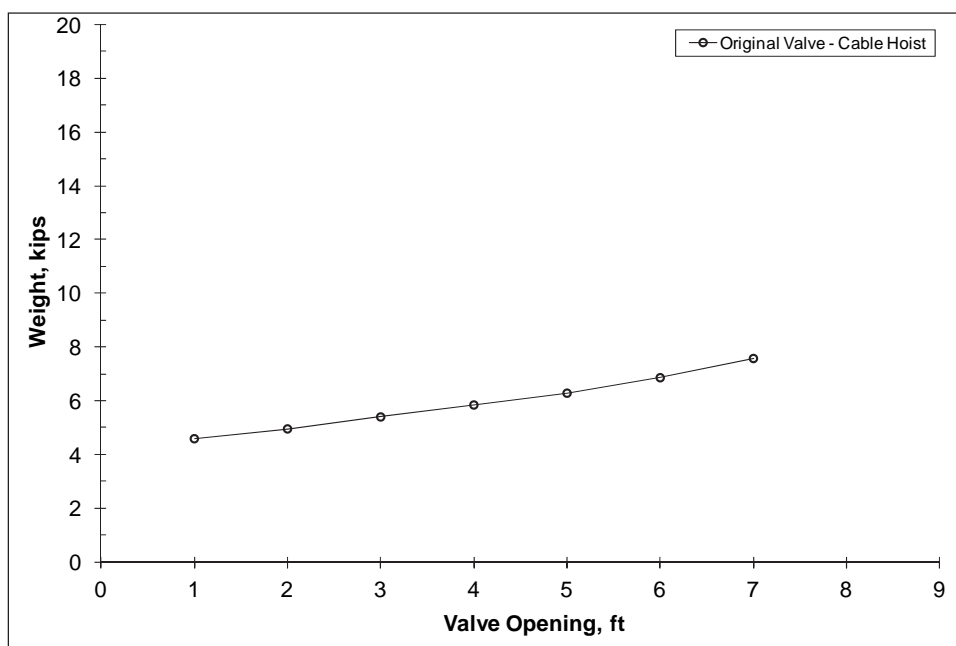


Figure 43. Chamber water-surface elevation vs. Hydraulic load: Original Valve

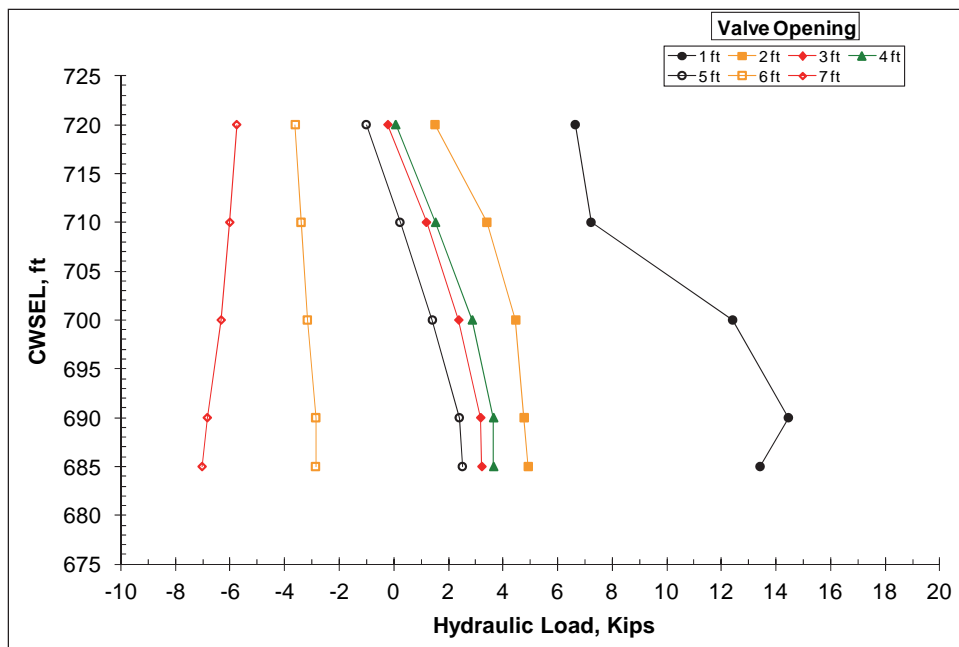


Figure 44. Hydraulic load vs. valve opening for varying: Original Valve

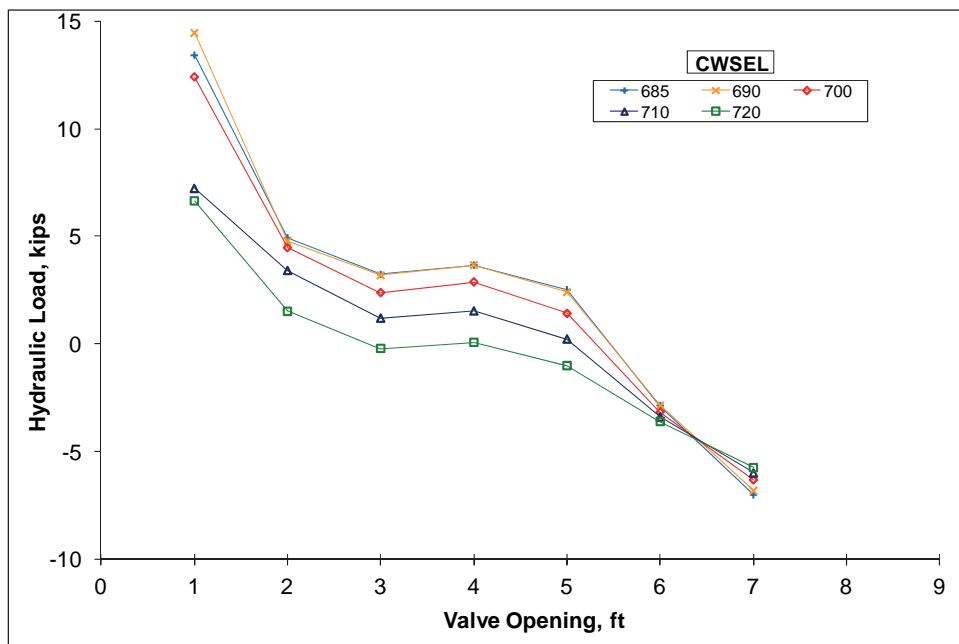
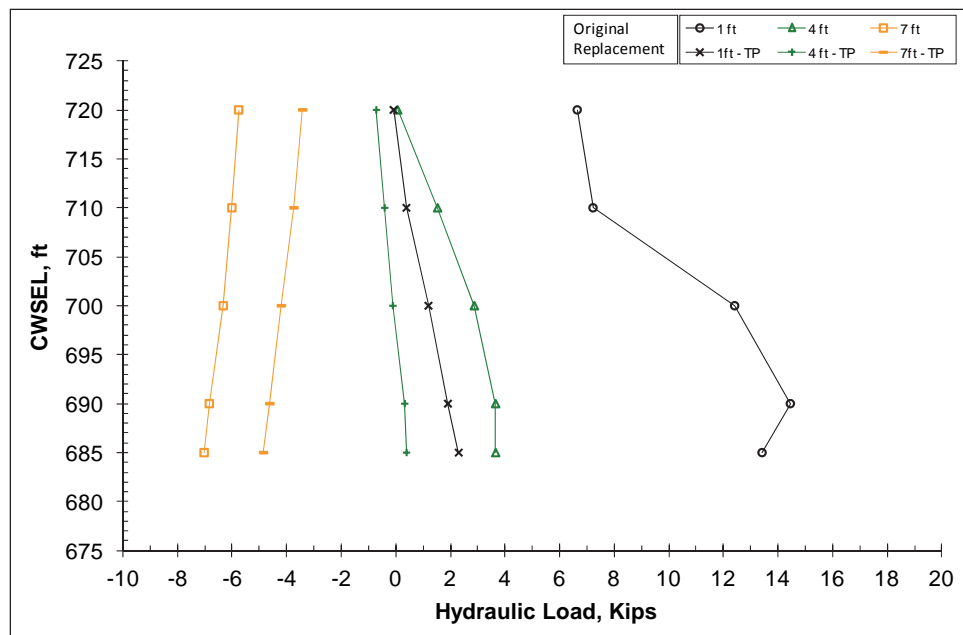




Figure 45. Select hydraulic loads for original valve and replacement valve with top plate



## **4 Conclusions and Recommendations**

### **Conclusions**

The hydraulic loads measured with the replacement valves and modifications were not considered excessive. The best valve performance based on hydraulic loads was the replacement valve without the top seal plate. With the top seal plate installed, upward forces were larger and valve vibrations were observed when it was fully-open. The valve-lowering tests showed that with the top seal plate and bottom plate installed, the upward forces were higher, and the valve moved very noticeably in the fully-open position.

The hydraulic loads measured with the original valve were larger than those measured with the replacement valve. No movement was observed during steady-state tests.

### **Recommendations**

The problems associated with the replacement valves due to upward movements appear to be caused by the top seal plate. A different seal plate adjustment design is recommended to eliminate or reduce the size of the top seal plate. The upward flow along the upstream side of the valve impacts the plate causing additional upward forces. Any bottom plate that has been installed on the valves should be removed when an opportunity arises. The next scheduled maintenance period is an adequate instance to remove the bottom plates and possibly modify the top seal plates.

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